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# Eco-estates: Diversity hotspots or isolated developments? Connectivity of eco-estates in the Indian Ocean Coastal Belt, KwaZulu-Natal, South Africa

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ABSTRACT

Population expansion and land transformation reduce biodiversity, potentially reducing environmental functionality. These effects are evident globally, and specifically in KwaZulu-Natal (KZN), South Africa, where land cover is being transformed for urbanisation. However, much of the urbanised areas incorporate differing levels of urban greening, which is improving local species and functional diversity. In recent years, a new form of urban greening in the form of eco-estate development has increased, which improves biodiversity and functional diversity. However, it has not yet been determined whether these eco-estates are connected to one another and the surrounding natural landscapes, allowing for natural species' colonisation, immigration and dispersal. In this study, we assessed whether eco-estates along the coast of KZN were ecologically connected to a) one another, and b) the surrounding natural landscape. Using a hybrid Least-cost Pathway/Ecological Circuit Theory approach, we modelled habitat suitability and dispersal requirements of a forest-specialised bird species in an effort to provide future development and management plans for eco-estates. Connectivity throughout coastal KZN was evident, with increased connectivity in areas of natural and urban indigenous forest and coastal thicket/dense bush and river systems (riparian zones), within which existing eco-estates were subsequently developed. Eco-estates were well connected to one another and surrounding natural landscapes, emphasising their importance as patches containing endangered indigenous forest and unprotected coastal thicket/dense bush and of increased species and functional diversity, improving local ecosystem functioning. We recommend that eco-estate development primarily focus on areas which have previously been transformed, to increase natural land cover. The intention to preserve, rehabilitate, and conserve natural land cover is fundamentally important if development is to take place within and surrounding areas of high connectivity to assist in increasing and conserving suitable habitats, improving functionality and connectivity in KZN, and assisting in offsetting the deleterious effects of future climate change.

## 1. Introduction

Increased population growth and the accompanied land transformation is one of the greatest threats to biodiversity (Groom, 2006; Hooke et al., 2012; Seto et al., 2014). The required land transformation for agricultural practices and urbanisation result in habitat loss, degradation, and fragmentation (Fahrig, 2003; Foley et al., 2005; Chazdon, 2008; Hooke et al., 2012), potentially reducing available resources (Foley et al., 2005; Groom, 2006) and preventing the flow of genetic material (Fahrig, 2003; Mueller et al., 2014). This is currently occurring throughout KwaZulu-Natal Province (KZN), South Africa, with 83% of the forest (Olivier et al., 2013) and 39% (increasing) grassland biomes (Mucina and Rutherford, 2006; O'Connor and Kuyler, 2009), respectively, of the Indian Ocean Coastal Belt (IOCB) having been transformed. The main drivers are agricultural; Sugarcane (*Saccharum officinarum*), banana (*Mus* sp.), and macadamia nut (*Macadamia integrifolia*) and plantations (*Eucalyptus* sp. and *Pinus* sp.) transformation interspersed with rural, urban, and industrial development (Mucina and Rutherford, 2006; Olivier et al., 2013; Jewitt et al., 2015; Ehlers Smith et al., 2017a,b, 2018a). However, over the last two decades a new form of urban development has increased along the coast of KZN, in the form of eco-estates, relatively large ( ± 400 ha) housing estates incorporating natural rehabilitation and conservation management plans (Grey-Ross et al., 2009; Alexander et al., 2018, 2019). The development of these eco-estates has mainly been on sugarcane land and are improving species and functional diversity of several taxa

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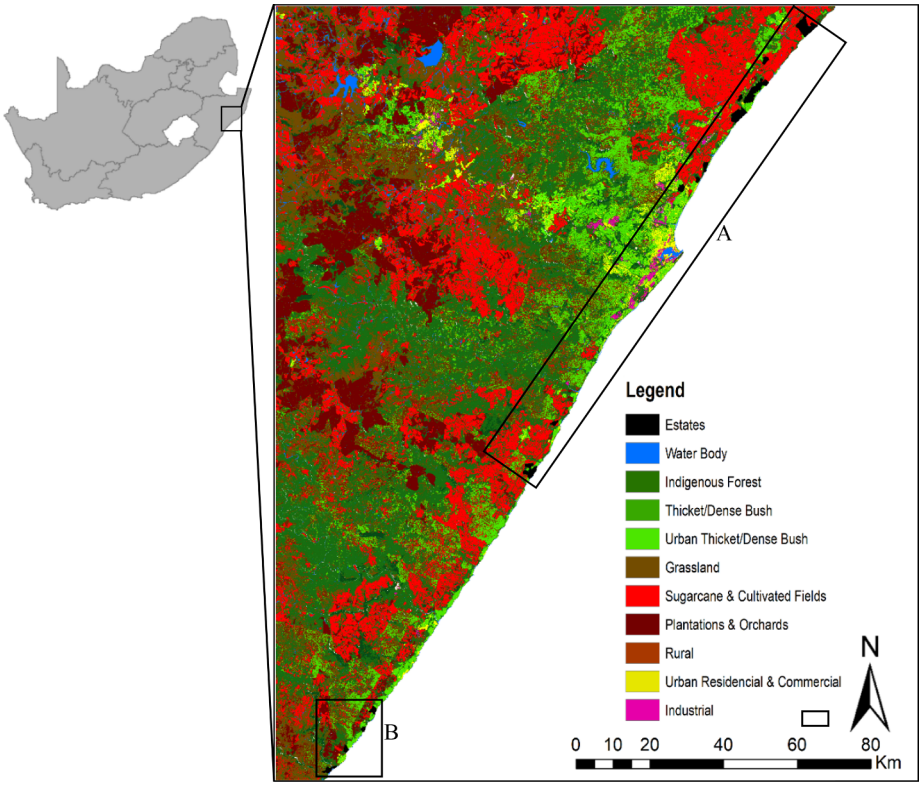


**Fig. 1.** Eco-estates situated in the A) northern and B) southern sample regions, in the Indian Ocean Coastal Belt (IOCB) along the coast of KwaZulu-Natal, South Africa, showing surrounding land cover types (GeoTerra Image, 2017).

(amphibian, avian, mammalian, and reptilian) in comparison to surrounding agriculture and urban land cover (Grey-Ross et al, 2009; Alexander et al., 2018, 2019).

Although eco-estates are improving local species and functional diversity, this may not benefit environmental functionality of KZN if these eco-estates are not showing sufficient connectivity to one another and the surrounding natural habitats. If disconnected, they would reflect isolated diversity hotspots in the agri-urban mosaic. However, if these eco-estates exhibit a degree of connectivity, they act as core patches or corridors of improved resources in a region where natural habitats are under human-induced transformation pressure (Cabeza, 2003; DEA, 2013). It is crucial to link efforts which improve functional diversity and connectivity for conservation planning (Marrul and Mallarch, 2005; McRae et al., 2008; Lindo et al., 2012) as functional diversity is influenced by connectivity (Thiele et al., 2018). By using functional diversity to drive connectivity planning, multiple conservation goals are met, including preservation of specialist species and habitats, improved ecosystems functioning across a region, and ultimately improved ecosystems services within both natural and anthropogenic landscapes, including nutrient cycling, hydrological regulation, seed dispersal, pollination, pest control, disease vector control, climate change adaptation, and gene flow (Sekercioğlu, 2006; Kool et al., 2013; Díaz Vélez et al., 2015; Alexander and Symes, 2016). New methods have been developed to assess and provision for the connectivity of landscapes, in the form of Ecological Circuit Theory, which aids in defining key areas facilitating or resisting species' natural dispersal or colonisation ability (McRae et al., 2008; Ehlers Smith et al., 2018b; Colyn et al., 2018). Ecological Circuit Theory, which utilises existing methods, such as graph-theory and least-cost pathways (Keitt et al., 1997; Adriaensen et al., 2003) has been applied in a variety of research fields and has been incorporated into ecology in the last decade (McRae et al., 2008; Rudnick et al., 2012). The theory bases its functioning on the relationships between current, voltage, and resistance in electrical circuits and the resulting directional flow and route selection of energy (Doyle and Snell, 1984). In this paper, we assessed the connectivity of eco-estates, and modelled the suitability of habitats through the IOCB, using a forest-specialised bird species as a surrogate of connectivity, the lemon dove (*Aplopelia larvata*). It was selected as a surrogate as it occurs throughout indigenous forest and coastal thicket/dense bush in KZN, is a sedentary forest specialist impacted by land transformation as a result of its restricted habitat, and has poor dispersion ability, ultimately reflecting the minimum requirements of habitat and connectivity conservation planning for the least dispersive species (Rudnick et al., 2012; Ehlers Smith et al., 2017c). Additionally, this species has been observed at sampled eco-estates (Alexander et al., 2018, 2019) and would theoretically be capable of dispersing between interconnected eco-estates and natural habitats under a certain threshold (~600 m; Ehlers Smith et al., 2018c). Research by Epps et al., (2011) and Braaker et al. (2014a,b) provide evidence that the use of single species or surrogates can be effective in conservation planning.

To investigate the adaptability of future and current eco-estate development, we assessed potential regions for future eco-estate development, considering both suitable and unsuitable areas for these developments. Land transformation in the form of urbanisation will not reduce while the human population continues to expand (Hooke et al., 2012; Seto et al., 2014) and climate change may be increasing the negative impacts of land transformation on diversity (Pereira et al., 2010; Garcia-Valdés et al., 2015). This implies that modelling of future habitat suitability is key for conservation planning (Kalle et al., 2017; Mezquida et al., 2018), especially for specialised species which exhibit reduced habitat niche availability and dispersibility (Pearson et al., 2014). With eco-estate development increasing in KZN, and often incorporating critically threatened indigenous coastal forest (DEA, 2013; Alexander et al., 2018, 2019), it is critical that future development be planned with the foresight of improving and conserving this biome and suggesting locations for development to either prevent future environmental degradation to indigenous forest habitats or to enhance sites in the KZN region, improving local species and functional diversity.

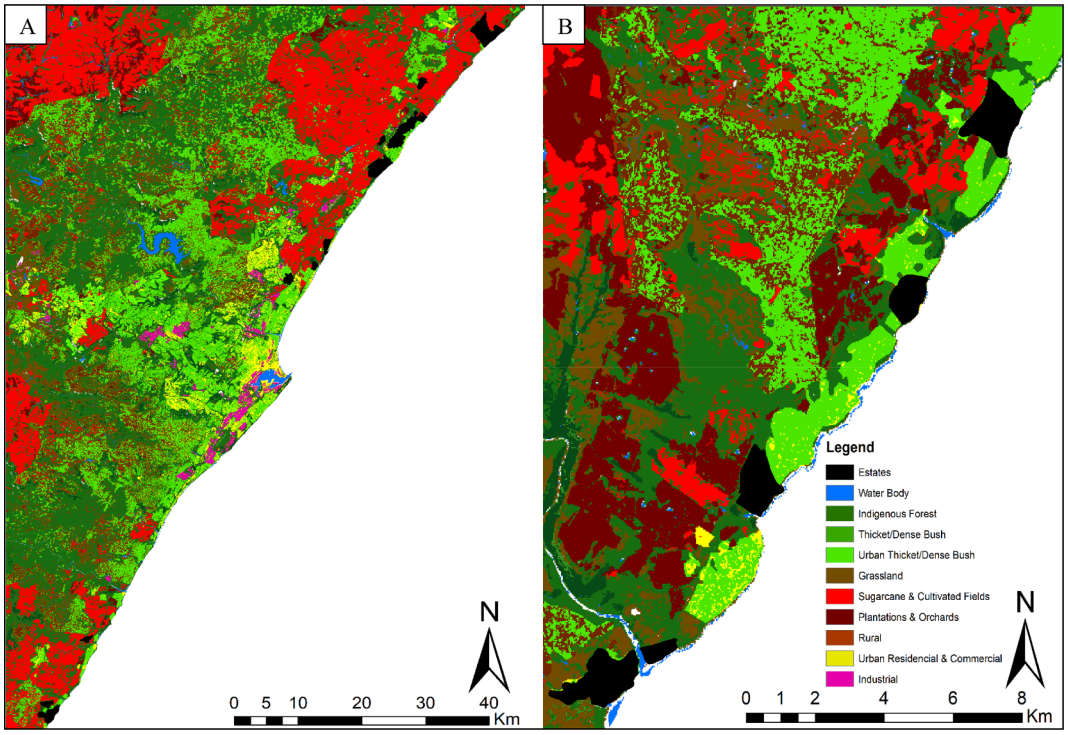


**Fig. 2.** Eco-estates occurring in the A) northern and B) southern regions, comprising differing bird communities (Hockey et al., 2005), in the Indian Ocean Coastal Belt (IOCB) along the coast of KwaZulu-Natal, South Africa, showing surrounding land cover types (GeoTerra Image, 2017).

## 2. Methods

### 2.1. Study sites

Eco-estates developed in the IOCB along the coast of KZN, between the Mtentwana River (31°6′23.55″S, 30°10′16.43″E) and Nanoti River (29°13′12.40″S, 31°29′12.18″E) were selected as core areas, based on research by Alexander et al. (2018, 2019). The selected sites contained the surrogate lemon dove, indigenous forest and coastal thicket/dense bush, and showed signs of improving species and functional diversity in the region (Figs. 1 and 2; Ehlers Smith et al., 2017c; Alexander et al., 2018, 2019); however, the distribution of the lemon dove incorporates all eco-estates evaluated. Sites were separated into two groups, comprising the differing northern and southern bird communities (Figs. 1 and 2; Hockey et al., 2005). The sample area comprised a variety of land-use types, from indigenous forest and grassland to urban and industrial zones (GeoTerra Image, 2017), which was mapped using the Geographic Information Systems (GIS) programme, ArcGIS v10.4 (Figs. 1 and 2; Environmental Systems Research Institute [ESRI], 2011). Naturally occurring, urban, and rural coastal thicket/dense bush, as classified by GeoTerra Image (2017) were grouped as suitable coastal thicket/dense bush (Figs. 1 and 2, and Appendix 1). All the sites were in close proximity to additional urban, agricultural, and natural landscapes (Figs. 1 and 2).

### 2.2. Habitat mapping

The Resistance and Habitat Mapper tool (McRae et al., 2013) in the Gnarly Landscape Utilities Package v.0.1.9 was used to create ESRI rasters of resistance and habitat suitability. We used the ecological requirements of lemon dove to inform the resistance and habitat suitability scores for each land-use type (c.f. Ehlers Smith et al., 2017c; Appendix 1), using the GeoTerra Image (2017) land-use type, and OpenStreetMap Contributors, 2015, roads rasters. Habitat values were scored on a continuous scale from 0 to 1; indigenous forest was selected as a primary habitat and assigned a score of 1, natural thicket/dense bush as secondary habitat and assigned a score of 0.8, and urban thicket/dense bush a score of 0.7 (Ehlers Smith et al., 2017c; Appendix 1). Resistance scores were designated on a continuous scale of 0–100; land-use types and roads were assigned resistance scores based on the species' habitat requirements and avoidances (Ehlers Smith et al., 2017c; Appendix 1). The Core Mapper tool (Shirk and McRae, 2013) in the Gnarly Landscape Utilities Package v.0.1.9 was used to create an ESRI raster of core habitats, based on the eco-estate sites incorporating suitable habitat (indigenous forest and coastal thicket/dense bush) and the surrogate species (Alexander et al., 2018, 2019).

### 2.3. Corridor mapping

Linkage Mapper (McRae and Kavanagh, 2011), PinchPoint and Barrier Mapper (McRae, 2012) were used to assess corridor connectivity, current flow (pinch-points or choke-points), and barrier distribution across corridors. The core habitat and resistance layers created above were used as inputs for Linkage, PinchPoint, and Barrier Mapper. The network adjacency method chosen for Linkage Mapper was set to Cost-weighted and Euclidean distance, and all five default processes were utilised to finalise analyses. The PinchPoint Mapper Cost-weighted Distance cut-off was set to 12,000 m (maximum distance between suitable habitat patches) and Barrier Mapper settings included a minimum and maximum detection radius of 500 m and 2,000 m, respectively, with a radius step up of 500 m.

## 3. Results

Habitat suitability increased with increased indigenous forest and coastal thicket/dense bush (natural and urban) specifically along river systems, and decreased with increased agriculture (sugarcane, cultivation, plantations, and orchards), rural, and urban landcover (Figs. 1–3A). Areas of reduced suitable habitat showed increased resistance (1 = least resistance and 161 = most resistance), mainly in agricultural and urbanised regions (Figs. 1–3B). Coastal KZN had large expanses of suitable habitat contained between and within urbanised

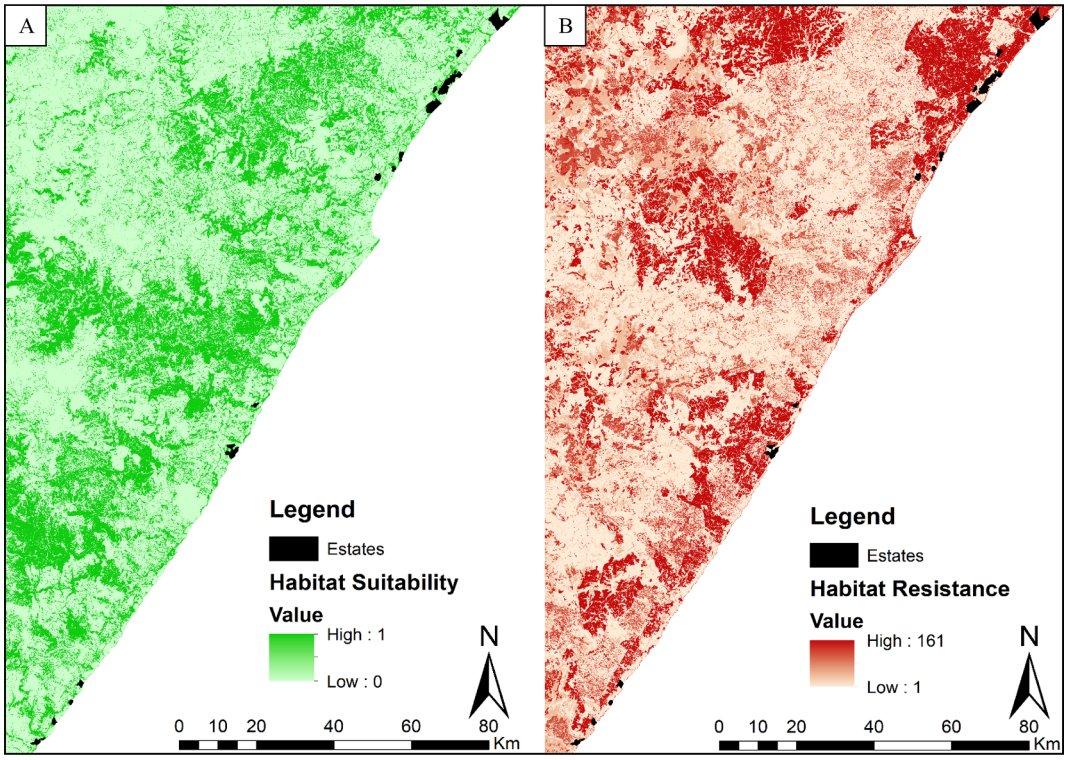


**Fig. 3.** Habitat A) suitability and B) resistance of Lemon dove (*Aplopelia larvata*) in KwaZulu-Natal, South Africa, based on ecological requirements and dispersal parameters. Calculated using Gnarly Landscape Utilities (McRae et al., 2013).

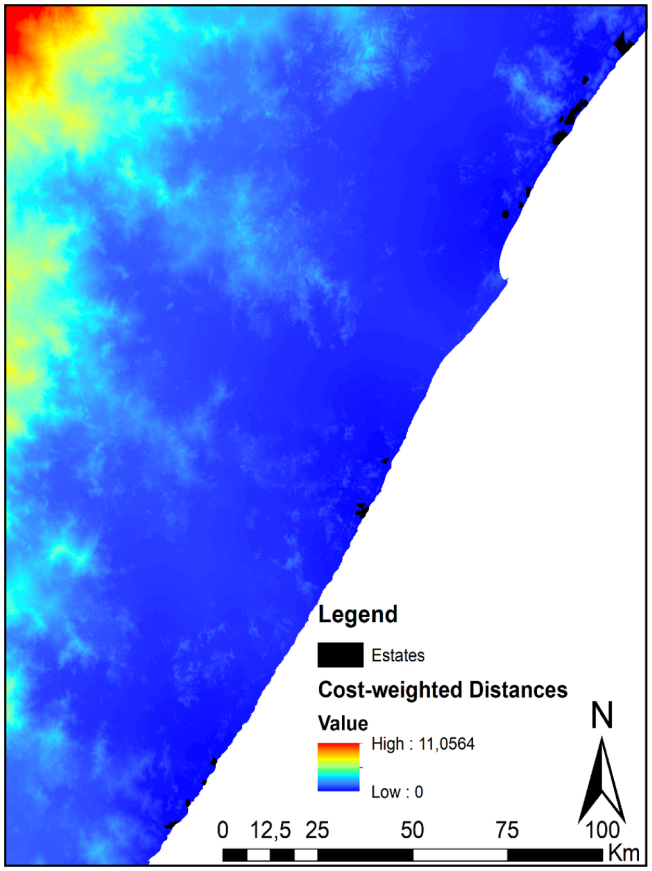


**Fig. 4.** Cost-weighted Distances, showing regions of maximal (0) and no (11,0564) connectivity in KwaZulu-Natal, South Africa, based on habitat suitability. Calculated using Linkage Mapper (McRae and Kavanagh, 2011).

settings (Figs. 1 and 3A). Cost-weighted Distances (0 = maximal connectivity and 11,0564 = no connectivity) showed that connectivity reduced with increasing distance inland (montane biome) and that the IOCB was connected throughout KZN for the surrogate taxon (Fig. 4). PinchPoint Mapper effectively highlighted regions of maximal (21,0535) and no connectivity (0) throughout KZN (Figs. 5–7). The greatest connectivity occurred in areas with increased indigenous forest, river systems (riparian sections), and natural and urban coastal thicket/dense bush and reduced in regions of increased agricultural and urban landcover (Figs. 1, 2, 5–7). Connectivity in the northern sample region of KZN was negatively influenced by agriculture, mainly sugarcane, with urbanisation that contained coastal thicket/dense bush improving connectivity (Fig. 6), whereas connectivity in the southern sample region was negatively influenced by agriculture, plantations, and orchards, but improved in areas of naturally occurring indigenous forest and coastal thicket/dense bush, primarily along river systems (Fig. 7).

## 4. Discussion

### 4.1. Are eco-estates connected?

Connectivity modelling using Ecological Circuit Theory revealed that the IOCB along the coast of KZN was well connected, and that developed eco-estates occurring within this region of connectivity were not only connected to one another, but were improving their connectivity to natural landscapes and fragmented patches. KwaZulu-Natal is possibly well connected as a result of existing and conserved suitable habitats, such as indigenous forest, which supports functionally rich diversity and the occurrence and abundance of natural coastal thicket/dense bush, which supports communities that are functionally similar to those occurring in natural indigenous forests (Ehlers Smith et al., 2017a,b, 2018a) connecting fragmented indigenous forest patches (Grafius et al., 2017; Ehlers Smith et al., 2018b; Colyn et al., 2018). This emphasises the importance of conserving high-quality landscapes

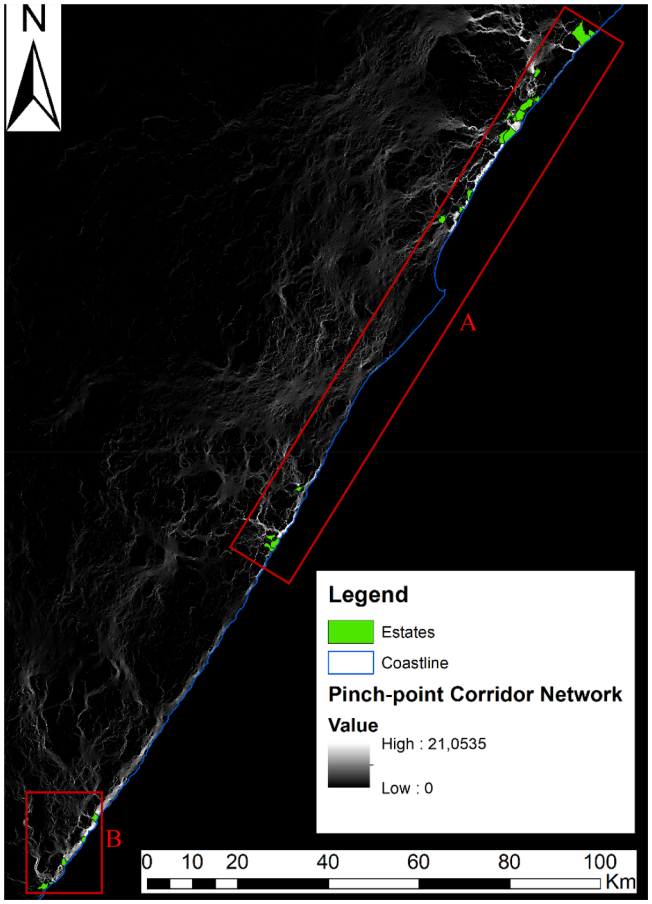


**Fig. 5.** Pinch-point connectivity between core habitats (eco-estates) of the A) northern and B) southern sample regions, through the Indian Ocean Coastal Belt (IOCB), KwaZulu-Natal, South Africa showing areas of maximal (21,0535) and no connectivity (0) in KwaZulu-Natal, South Africa. Calculated using Pinchpoint Mapper (McRae, 2012).

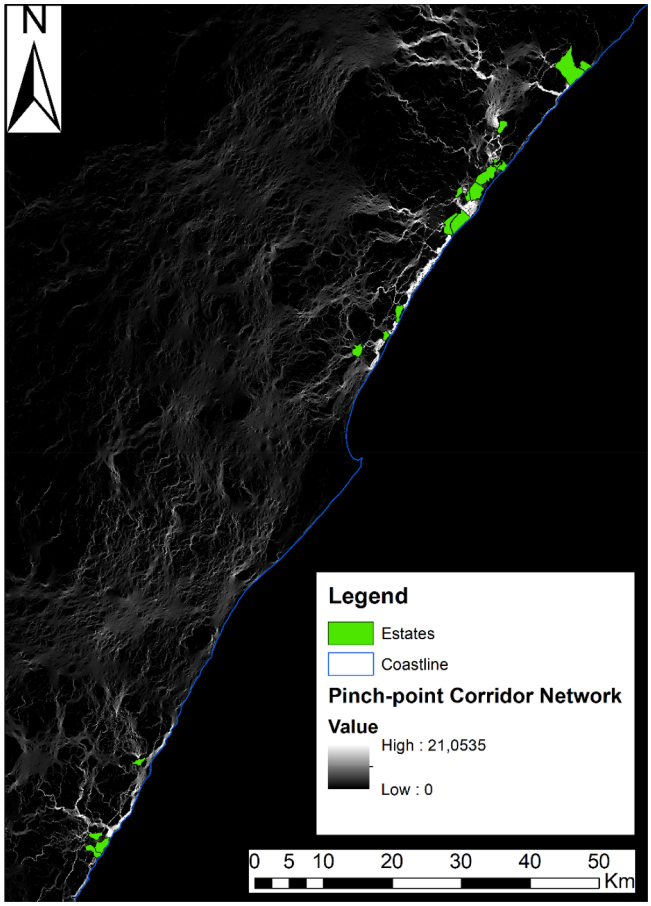


**Fig. 6.** Pinch-point connectivity between core habitats (eco-estates) of the northern sample region, KwaZulu-Natal, South Africa showing areas of maximal (21,0535) and no connectivity (0) in KwaZulu-Natal, South Africa. Calculated using Pinchpoint Mapper (McRae, 2012).

(Hodgson et al., 2011), primarily unprotected expanses and patches of coastal thicket/dense bush (Ehlers Smith et al., 2017a,b, 2018a). Additionally, rehabilitated and conserved indigenous forest and coastal thicket/dense bush occurring in urbanised areas contributes to linking existing and fragmented natural patches. Urban green spaces globally, and specifically in KZN, have aided in improving species and functional diversity (DeGraaf and Wentworth, 1986; Blair, 1996; Sandström et al., 2006; Sperling and Lortie, 2009; Rollinson et al., 2014; Widdows et al., 2015; McPherson et al., 2016; Singh and Downs, 2016; Patterson et al., 2018), with many urban green spaces linking existing natural and protected areas with one another, and showing connectivity between themselves (Rudd et al., 2002; Sperling and Lortie, 2009; Kong et al., 2010; Braaker et al., 2014a,b). Connectivity through naturally occurring indigenous forest and coastal thicket/dense bush was more apparent in the southern sample region as a result of reduced urbanisation in comparison to the northern sample region, and agriculture and plantations occurring across a greater area with interspersed patches of natural land cover. Conversely, urbanisation was more dominant in the northern sample region, but incorporated indigenous forest and coastal thicket/dense bush interspersed by agriculture (mainly sugarcane). This conservation of natural habitats within urbanised regions of KZN is a result of the Durban Metropolitan Open Space System (D'MOSS), a conservation and management effort of 78,000 ha of land and water in Durban, which incorporates areas of high biodiversity value (Roberts, 1994; eThekwini Municipality, 2007; Shih and Mabon, 2017).

The main impediment to connectivity in KZN was unsuitable habitats (St. Louis et al., 2014; Grafius et al., 2017) such as agriculture, plantations and orchards, which is predictable due to the vast expanses of natural land cover which has been transformed for these practices (Midgley et al., 1997; Mucina and Rutherford, 2006; Ehlers Smith et al., 2017a,b, 2018a). However, it is promising to observe that agricultural and plantation practices occurred along bands between the coast line and ± 500 m inland, after which they reduced inland and were replaced by increasing indigenous forest and thicket/dense bush (*pers. obs.*). Fragmented coastal and inland patches of natural land cover were connected along rivers and their corresponding natural land cover (river systems), resulting in arcs of connectivity, specifically in regions of increased agricultural and plantation practices, suggesting that river systems (suitable habitat) are a highly valuable component, positively influencing connectivity in areas of unsuitable habitat in KZN (Hodgson et al., 2011; St. Louis et al., 2014; Grafius et al., 2017). These patterns in connectivity along the coast of KZN provided us with future development and management frameworks to assist in maintaining and improving connectivity and maintaining ecosystem functionality (Marrul and Mallarch, 2005; McRae et al., 2008; Lindo et al., 2012; Rudnick et al., 2012).

### 4.2. Future management of natural land cover

The most important management suggestion would be to preserve indigenous forest, which is already under formal protection, and conserve coastal thicket/dense bush, which has no protection status, and is rapidly being cleared for agriculture (Ehlers Smith et al., 2017a,b). This land-cover type is the most abundant naturally-occurring habitat type in coastal KZN (Mucina and Rutherford, 2006; Ehlers Smith et al.,

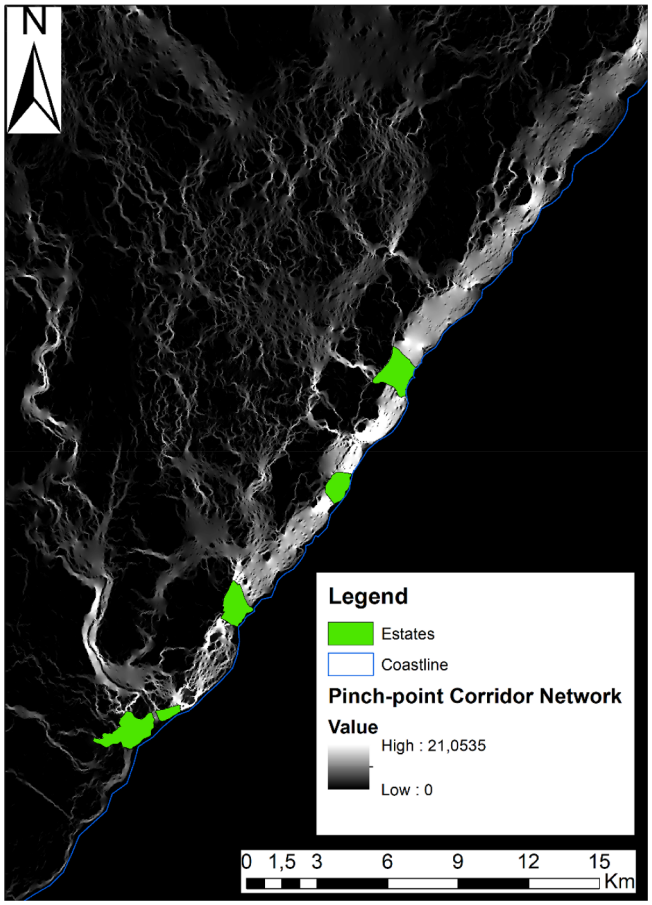


**Fig. 7.** Pinch-point connectivity between core habitats (eco-estates) of the southern sample region, KwaZulu-Natal, South Africa showing areas of maximal (21,0535) and no connectivity (0) in KwaZulu-Natal, South Africa. Calculated using Pinchpoint Mapper (McRae, 2012).

2017a,b) and thus influences the species which inhabit and utilise it, and the resulting ecosystem services that these communities provide (Pardini et al., 2005; Petchey and Gaston, 2002; Adams et al., 2006; Wilby and Perry, 2006; Mouchet et al., 2010; Ehlers Smith et al., 2015, 2018a). By conserving natural land cover, connectivity and regions for connectivity, will be maintained and possibly expanded. Eco-estates in KZN contain sections of existing natural indigenous forest and coastal thicket/dense bush; however much of these habitats are destroyed prior to development (*pers. obs.*). In regions of degraded landscapes such as agricultural and urban areas, rehabilitation of naturally occurring and high-quality land cover should be the main priority (Hodgson et al., 2011). Increasing natural landscapes in and around degraded landscapes improves species and functional diversity (Mouchet et al., 2010; Ehlers Smith et al., 2017a,b; Alexander et al., 2018, 2019), and connectivity between fragmented natural habits (Cabeza, 2003; Davis and Wilcox, 2013; Carrara et al., 2015; Ehlers Smith et al., 2018b). This practice has taken place in KZN through the D'MOSS program and eco-estate development (Roberts, 1994; eThekwini Municipality, 2007; Grey-Ross et al., 2009; Shih and Mabon, 2017; Alexander et al., 2018, 2019) and should become standard procedure with regards to any degraded landscapes, especially agricultural land cover (Alexander et al., 2019).

### 4.3. Future development

With regards to future developments, whether commercial, urban, or eco-estates, there are two fundamental development guidelines relating to site selection.

1) If the development requires destruction/clearing of natural land cover, without the intention of rehabilitation and future conservation, the site selection should be in a region of poor connectivity, and ideally not occurring in immediate contact with regions of high connectivity. These regions are already degraded and have little to no positive influence on connectivity (St. Louis et al., 2014; Grafius et al., 2017) and thus it may be deemed acceptable to develop without the intention to rehabilitate natural land cover. It is advisable to rehabilitate natural land cover on or surrounding the development site to improve local species and functional diversity, and ultimately connectivity.
2) Development with the intention to preserve, rehabilitate, and conserve natural land cover, which can be further categorised can occur in regions of high connectivity:
   2.1) Development with the intention to degrade but rehabilitate natural land cover may occur in regions in contact with high connectivity areas (but is less advisable as primary natural landscapes are preferable to secondary regenerated landscapes), as this is less likely to influence the natural land cover and its connectivity value, but it may also allow for overall expansion of natural land cover, resulting in increased connectivity in the area.
   2.2) Development with the intention to preserve and further rehabilitate and conserve natural land cover (eco-estates) can occur in regions of high connectivity, as natural habitats must not be degraded (in order to uphold the conservation practices of eco-estates) allowing further rehabilitation and expansion of suitable land cover. It is fundamentally important to maintain Ecological Land-use Complementation (natural and effective structuring and orientation of natural habitats) during and after development (Colding, 2007), as suitable habitats providing resources and allowing for species' persistence would be maintained or rehabilitated (Pope et al., 2000; Wood and Pullins, 2002; Quin et al., 2004; Ehlers Smith et al., 2017c, 2018a) and fragmentation of suitable habitats would be reduced (Clergeau et al., 2001; Fahrig, 2003; Morimoto et al., 2006; Ehlers Smith et al., 2017b, 2018b).

Climate change coupled with land transformation has a synergistic deleterious effect on biodiversity (Pereira et al., 2010; Garcia-Valdés et al., 2015) and with increased land transformation occurring in KZN (Mucina and Rutherford, 2006; Olivier et al., 2013; Ehlers Smith et al., 2017a,b) it is critical that coastal indigenous forest be conserved effectively to account for future climatic changes (Kambuj et al., 2016). Currently, up to 75% of natural landscape in KZN is unstable and requires increased conservation (Jewitt et al., 2017), which does not correspond with the suggested 50% of landscape management required for species' persistence (Noss et al., 2012). This emphasises the need to conserve and further rehabilitate the regions of increased connectivity in an effort to offset the effects of future climate change (Kool et al., 2013). Eco-estates are a promising means of providing shelter and job opportunities to an ever-increasing population and conserving existing and future natural land cover.

It must be noted that these suggested regions of connectivity are modelled on a forest-specialised bird, which has been observed utilising suggested connected networks (St. Louis et al., 2014). Additionally, the use of a specialist surrogate taxa requiring the minimum connectivity parameters reflects the requirements of functionally similar and generalist species (Rudnick et al., 2012). However, many of the eco-estates are fenced and are thus impermeable to mammal species and therefore mammal populations should be managed accordingly, through stock rotation and quota management. This study may be specific to avian species, but it provides the first comprehensive study highlighting the connectivity of eco-estates in KZN and their connectedness to surrounding natural landscapes, some of which are critically endangered. It therefore provides robust and empirically-driven ecological development and management plans with regards to eco-estates, and allows for future research to expand on how eco-estates are positively

influencing functional diversity and connectivity in the KZN, ensuring they are worthy of their moniker.

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## Appendix

**Appendix 1**
Habitat suitability and resistance values predicted by lemon dove (*Aplopelia larvata*) ecology for land-class features within the Indian Ocean Coastal Belt (IOCB) matrix, KwaZulu-Natal, South Africa.

| Land-class description | Habitat Value | Resistance value |
|---|---|---|
| Water seasonal | 0 | 40 |
| Water permanent | 0 | 20 |
| Wetlands | 0 | 40 |
| Indigenous forest | 1 | 0 |
| Thicket/Dense bush | 0.8 | 0 |
| Woodland/Open bush | 0 | 20 |
| Grassland | 0 | 40 |
| Low shrubland | 0 | 30 |
| Cultivated comm fields (high) | 0 | 100 |
| Cultivated comm fields (med) | 0 | 90 |
| Cultivated comm fields (low) | 0 | 80 |
| Cultivated comm pivots (high) | 0 | 100 |
| Cultivated comm pivots (med) | 0 | 90 |
| Cultivated comm pivots (low) | 0 | 80 |
| Cultivated orchards (high) | 0 | 100 |
| Cultivated orchards (med) | 0 | 90 |
| Cultivated orchards (low) | 0 | 80 |
| Cultivated permanent pineapple | 0 | 100 |
| Cultivated subsistence (high) | 0 | 100 |
| Cultivated subsistence (med) | 0 | 90 |
| Cultivated subsistence (low) | 0 | 80 |
| Cultivated cane pivot - crop | 0 | 100 |
| Cultivated cane pivot - fallow | 0 | 100 |
| Cultivated cane commercial - crop | 0 | 100 |
| Cultivated cane commercial - fallow | 0 | 100 |
| Cultivated cane emerging - crop | 0 | 100 |
| Cultivated cane emerging - fallow | 0 | 100 |
| Tree plantations/Woodlots mature | 0 | 20 |
| Tree plantation/Woodlots young | 0 | 80 |
| Tree plantation/Woodlots clear-felled | 0 | 100 |
| Mines 1 bare | 0 | 100 |
| Mines 2 semi-bare | 0 | 100 |
| Mines water seasonal | 0 | 100 |
| Mines water permanent | 0 | 100 |
| Mine buildings | 0 | 100 |
| Erosion (donga) | 0 | 100 |
| Bare none vegetated | 0 | 100 |
| Urban commercial | 0 | 100 |
| Urban industrial | 0 | 100 |
| Urban informal (dense trees/bush)* | 0.7 | 0 |
| Urban informal (open trees/bush) | 0 | 40 |
| Urban informal (low veg/grass) | 0 | 80 |
| Urban informal (bare) | 0 | 100 |
| Urban residential (dense trees/bush)* | 0.7 | 0 |
| Urban residential (open trees/bush) | 0 | 40 |
| Urban residential (low veg/grass) | 0 | 80 |
| Urban residential (bare) | 0 | 100 |
| Urban school and sports ground | 0 | 100 |
| Urban smallholding (dense trees/bush)* | 0.7 | 0 |
| Urban smallholding (open trees/bush) | 0 | 40 |
| Urban smallholding (low veg/grass) | 0 | 80 |
| Urban smallholding (bare) | 0 | 100 |
| Urban sports and golf (dense tree/bush)* | 0 | 0 |
| Urban sports and golf (open tree/bush) | 0.8 | 40 |
| Urban sports and golf (low veg/grass) | 0 | 80 |
| Urban sports and golf (bare) | 0 | 100 |
| Urban township (dense trees/bush)* | 0.7 | 0 |
| Urban township (open trees/bush) | 0 | 40 |
| Urban township (low veg/grass) | 0 | 80 |
| Urban township (bare) | 0 | 100 |

(*continued on next page*)

**Appendix 1** (*continued*)

| Land-class description | Habitat Value | Resistance value |
|---|---|---|
| Urban village (dense trees/bush)* | 0.7 | 0 |
| Urban village (open trees/bush) | 0 | 40 |
| Urban village (low veg/grass) | 0 | 80 |
| Urban village (bare) | 0 | 100 |
| Urban built-up (dense trees/bush)* | 0.7 | 0 |
| Urban built-up (open trees/bush) | 0 | 40 |
| Urban built-up (low veg/grass) | 0 | 80 |
| Urban built-up (bare) | 0 | 100 |
| Motorway | 0 | 60 |
| Motorway_link | 0 | 60 |
| Primary road | 0 | 60 |
| Primary_link | 0 | 60 |
| Trunk road | 0 | 40 |
| Trunk_link | 0 | 40 |
| Secondary road | 0 | 40 |
| Unclassified road | 0 | 5 |
| Residential road | 0 | 5 |
| Tertiary road | 0 | 5 |

* Grouped to reflected urban coastal thicket/dense bush.

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